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Report to Congressional Requesters

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EMBEDDED COMPUTERS

Navy's Approach to Developing Patrol Aircraft Avionics System Too Risky

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Information Management and
Technology Division

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The Honorable John Conyers, Jr.
Chairman, Legislation and National
Security Subcommittee
Government Operations Committee
House of Representatives

The Honorable Frank Horton
Ranking Minority Member, Legislation
and National Security Subcommittee
Government Operations Committee
House of Representatives

The Navy plans to buy complex avionics computer systems, and related communications equipment and sensors, for submarine patrol aircraft. This acquisition, designated the Update IV Program, is intended to provide the Navy with the capability to locate, identify, and attack the expected threat of more quiet submarines. Between September 1990 and May 1993, the Navy plans to buy 28 of the avionics systems at a cost of $496 million. Although its plans are uncertain, the Navy's total purchase could be for up to 240 systems at a cost of about $2.1 billion.

This report reviews your offices' October 1989 request to review the Update IV Program, and is part of your overall request to review the Department of Defense's acquisition of computer systems embedded in weapon systems. Our objectives were to determine whether (1) the Navy plans to adequately test the avionics computer systems before buying them, and (2) Navy management oversight of these computer systems has occurred. A detailed discussion of our objectives, scope, and methodology is contained in appendix I.

Results in Brief

The Navy is taking a high risk approach in acquiring a new and complex computer-based avionics system for its patrol aircraft. Although the Navy originally planned to thoroughly test this system before buying more than four, program delays led the Navy to postpone complete testing. This is clearly contrary to (1) Defense policies which, when followed, should be effective in mitigating computer system development risks and (2) the principle of "fly before you buy."

Specifically, the Navy plans to:

- Continue developing software (i.e., coding) before it has approved the design specifying what the software should do and how well it should do it;
- Buy 28 of the avionics systems before all testing is successfully completed; and
- Use a model of one of the system's processors during testing that is not an accurate representation of the final version.

The Navy is planning to follow this high risk approach because it believes that any further delays will cause it to miss fixed-price contract option deadlines and increase contract costs. The Navy, however, has not prepared any detailed analysis to support its contention that contract costs will increase. In addition, the Navy's position fails to consider the costs of buying 28 systems that may not work as intended and may require expensive fixes, assuming they can be fixed. As we previously reported, it can be six to ten times more costly to correct a software problem after a system in placed in operation than it is during early system development.

We recognize that adhering to Defense policies might increase acquisition costs. But possible cost increases do not justify spending almost $500 million on a system that has not been thoroughly tested. If the Navy finds that missing contract option deadlines will be prohibitively expensive, it must decide whether this avionics system is affordable.

Background

In February 1985, the Navy began the $2.1 billion Update IV Program to provide submarine patrol aircraft with modern avionics computer technology and sensors. These long range, land-based patrol aircraft are deployed globally to find, identify, and attack new classes of very quiet enemy submarines. The Navy planned to install the new avionics computer system on 108 existing P-3 aircraft and an estimated 125 new P-7 aircraft.[1] However, the Navy has since terminated the P-7 aircraft program, and is now considering other alternatives such as buying more P-3 aircraft or reducing the number of avionics systems to be bought.

The Update IV Program includes computer systems that process and display sensor data, and control aircraft sensor, communication, navigation, and armament subsystems. In 1987, the Navy awarded an Update

[1]The remaining 7 of the 240 total avionics systems are for engineering development modeling.

IV system integration contract having multiple contract production options, including an initial four that are fixed-price. The system's software is currently being developed (i.e., coded) and undergoing early laboratory testing. The first contract option deadline is September 1990. Table 1 shows development milestones, the first three contract option quantities, and funding requirements.

Table 1: Development Milestones, First Three Contract Options, and Funding Requirements

Dollars in millions

Milestones	Quantity	Funding Requirements[a] Production	Support	Total
Option 1 September 1990	4	$68.3	$21.2	$89.5
Option 2 May 1992	12	$153.9	$41.1	$195.0
Option 3 April 1993	12	$174.3	$37.6	$211.9
Totals	**28**	**$396.5**	**$99.9**	**$496.4**

[a]Funding requirements have not been revised to reflect any near-term impact of terminating the P-7 program.

Navy Did Not Specify Software Requirements Before Development

The Update IV system integration contract requires the contractor to prepare detailed functional and performance specifications for each software subsystem. According to Defense software development policy,[2] such specifications are necessary to establish a requirements baseline for detailed software design and development. Contrary to this policy, however, the Navy is allowing the Update IV contractor to develop software before subsystem specifications are completed and approved. The Defense Department has reported[3] and we agree that failure to define complete specifications before developing software may not only jeopardize software quality, but can also increase development costs and delay project completion. This concern was raised in a risk analysis prepared by the Navy laboratory monitoring the contractor's performance. As stated in the analysis, developing the software that will perform some of the system's mission functions (e.g., communication and navigation processing, nonacoustic sensor management, search stores and weapons management, and inflight performance monitoring) at the same time that software requirements are being specified affords

[2]Military Standard 2167A, Defense System Software Development, February 1988.

[3]Proceedings of the Joint Logistics Commanders Joint Policy Coordinating Group on Computer Resource Management (Aug. 1979).

minimal time for much-needed design validation and greatly increases the risk that the software will be unacceptable.

As of June 1990, the Navy had not approved most subsystem specifications for the Update IV avionics system, yet the contractor had written about 80 percent of the software and had started testing to determine whether individual units of code performed their functions. Although draft specifications exist, the Navy has approved or conditionally accepted only a third of them because the remaining two thirds either do not meet the requirements of the system level specifications or have yet to be evaluated. Consequently, the avionics software is being coded against a moving baseline, and the Navy currently lacks firm criteria for testing and contract acceptance. This has not only resulted in an estimated 3-month delay in software testing, but more importantly could result in (1) additional coding costs once the software design is finalized or (2) a system which does not meet all requirements set forth in the system specification.

We reviewed the status of the Update IV subsystem specifications as of June 1990, and found that the Navy had approved only 3 of 93 specifications. Of the remaining 90 specifications, 30 had received conditional approval pending incorporation of minor comments, 17 were unacceptable and rejected because they did not meet requirements in the overall system specification, and 43 were still under review. Examples of rejected specifications include those for the tactical mission subsystem[4] and the systems management software,[5] without either of which the avionics system could not accomplish the antisubmarine warfare mission objective. Although approval of all subsystem specifications was targeted for August 1990, program officials stated that approval will not occur before September 1990.

Adequate Testing Will Not Occur Prior to Production Decisions

The Navy's planned testing of the Update IV Program will not provide reasonable assurance that this computer-based avionics system is ready for full rate production. Testing validates that a system meets its functional and performance requirements and can effectively perform the intended mission. For the Update IV Program, testing is particularly

[4]This subsystem provides environmental analysis aids, correlation, tactical execution, tactical and nonacoustic situation management, classification, and tactical planning aids.

[5]This software is responsible for recording, data base management, displays and controls, and real-time executive management functions.

important because the system's software is estimated at about one million lines of Ada code,[6] and the Navy laboratory monitoring the Update IV Program considers Ada's use to be a high risk because relatively little experience has been gained with Ada in stringent, real-time environments.[7] Additionally, this software performs critical mission functions. For example, the avionics system's software includes sophisticated algorithms,[8] such as multisensor target tracking and decision aids, to help crew operators work with the massive number of sensor data inputs associated with locating, tracking, and targeting submarines. The correctness and effectiveness of such complex software systems is ascertained by thorough testing. Failure to conduct rigorous testing greatly increases the possibility of producing and deploying a system that fails to meet its mission requirements.

Computer system testing is incremental and can be viewed as having two major components—developmental testing and operational testing. Generally, the purpose of developmental testing is to determine whether a system meets the requirements in its specifications, while operational testing determines whether a system that has been designed according to its specifications meets mission requirements. More specifically, early developmental tests focus on whether individual software modules perform as required in the specification. Later developmental testing addresses whether and how well the integrated modules perform required functions (i.e., how fast, how reliable, how accurate, how often) in a laboratory that realistically simulates an operational setting. Following this laboratory integration testing, the complete system is tested with actual users in a true operational setting. This operational testing is sometimes conducted in two phases, with the first phase showing the system's "potential" mission effectiveness and justifying initial rate production quantities, and the second phase demonstrating the system's ability to meet the mission requirement and justifying full rate production. The above described testing progression emphasizes the benefits of finding problems early in the development process, when they are cheaper to correct.

[6]Ada is a relatively new high-order language designed for use in real-time computer systems.

[7]Such systems must be able to obtain data from an activity or process, perform computations, and respond quickly enough to affect the outcome of that activity or process. Depending on the application, a response may be required in seconds or in milliseconds. Aircraft avionics use real-time computer systems.

[8]Well-defined steps for solving a problem.

Developmental Testing Hampered by Contractor Laboratory Test Facilities

The contractor is responsible for developing two software integration laboratories, one for testing the avionics system's acoustic capabilities and one for testing its nonacoustic capabilities. These laboratories include computer hardware and software that simulate the avionics system's operational conditions and provide an environment for testing the system.

The contractor is currently more than 1 year late in developing the two laboratories. As a result, the extent of laboratory testing that can be performed before the first production options expire has been reduced considerably. Moreover, the Navy's technical review of the contractor's laboratory facilities has raised some doubt as to whether the laboratories' simulation programs accurately simulate the mission environment. For example, the review questions whether the laboratory simulation includes a realistic number of targets.

Operational Testing Will Not Be Completed Before Systems Are Bought

Navy policy[9] requires full operational testing before a system enters full rate production. Additionally, the National Defense Authorization Act for Fiscal Years 1990 and 1991, dated November 29, 1989, (P.L. 101-189) defines low-rate initial production of new weapons systems as the minimum quantity necessary to (1) provide production-configured or representative articles for operational tests, (2) establish an initial production base for the system, and (3) permit an orderly increase in the production rate sufficient to lead to full rate production upon successful completion of operational testing. Navy policy[10] uses a similar definition. Consistent with these policies and definitions, the Navy initially planned to (1) approve what it called limited rate production in April 1991 for four avionics systems (i.e., exercise the first contract option), (2) complete full operational testing in February 1992, and (3) approve full rate production in April 1992 to buy as many as 24 more systems (i.e., exercise second and third contract options).

The Navy revised this initial plan in response to contractor delays in developing the system and government delays in providing certain required government-furnished equipment.[11] Under the revised plan, the Navy has delayed full operational testing by more than 2 years until the

[9]Chief of Naval Operations Instruction 3960.10C, Test and Evaluation, September 1987.

[10]Chief of Naval Operations Instruction 5000.42C, Research, Development and Acquisition Procedures, May 1986.

[11]An enhanced acoustic processor is being separately developed by the Navy and will be provided to the Update IV contractor for integration with other avionics system components.

first quarter of 1994, but still plans to buy the initial four systems in September 1990 (now calling this pilot production instead of limited rate production) and the additional 24 between May 1992 and April 1993 (now calling this limited rate instead of full rate production). This means that the Navy plans to buy as many as 28 systems before it knows whether the system can satisfy the mission requirement. When questioned, Navy program and oversight officials stated that their primary reason for increasing their initial rate quantities from four to 28 was the need to exercise favorable, fixed-price contract options on time. These officials further stated that under different contractual circumstances, they would not buy so many systems before completing full operational testing. In our opinion, the Navy's decision to expand initial rate production to 28 systems is inconsistent with Navy policy to hold limited rate production at minimum levels before completing full operational testing, and consequently creates an unacceptable risk of buying a large number of systems that may not be mission effective.

We do not support the Navy's revised plan, and are concerned that without the results of full operational testing, the Navy will not have the information it needs to make a prudent management decision on whether to buy more than the initial four systems. Moreover, given that the revised plan calls for delivery of twelve avionics systems to an operational squadron at the same time operational testing is occurring, the Navy risks sending systems to the field that do not work.

Navy officials also contend that they need to exercise production options on schedule to maintain price guarantees, adding that costs could increase significantly if the contract is renegotiated. However, their estimates of cost increases are not supported by detailed analysis. Although the Navy began an analysis to better estimate the effect of contract renegotiation on costs, this analysis was not completed because of difficulties in obtaining requisite data from the contractor. Additionally, the Navy's estimates fail to recognize the substantial time and expense that could be incurred if an avionics system is delivered to the fleet with extensive hardware and software problems. As we previously reported,[12] it can be six to ten times more costly to correct a software discrepancy after a system is placed in operation than it is during early system development. Also, even though the Navy program manager stated that it would be difficult to renegociate the contract to allow the Navy to exercise production options after full operational testing, the

[12]Embedded Computers: Navy Not Ready to Buy Avionics Computers for Its LAMPS Mk I Helicopters (GAO/IMTEC-90-54, May 31, 1990).

Navy has recently negotiated extending both the third and fourth production options in the Update IV contract by 6 months at no additional cost to the government.

Last, program officials stated that their current plan allows for adequate testing before making production decisions, noting that they have extended the initial phases of planned operational testing by several months. However, this extended testing will still not support a full rate production decision because it will only assess "potential" system effectiveness. According to Navy policy, such testing only provides an adequate basis for producing limited rate production quantities. It does not constitute full operational testing, which is necessary to demonstrate system mission effectiveness and is required to approve full rate production. Moreover, this extension of initial operational testing will use a model of one of the avionics system processors that is not an accurate representation of the version of this processor to be produced (see next section).

Processor Model Not Representative

An enhanced acoustic processor[13] is being separately developed and will be given to the Update IV contractor for integration with the other avionics system components. Originally, the Navy was to provide the processor in April 1990. However, hardware and software problems have delayed the processor's development, causing its delivery to the Update IV contractor to slip to November 1990. According to program officials, acoustic processing is the most critical function that the Update IV Program will perform.

Because of delays in developing this processor, initial operational testing to determine whether to exercise the second contract option will use a Navy-provided model of the processor. The validity of the initial operational testing then will depend on how accurately the model simulates the acoustic processor. However, the model the Navy has provided the contractor has less functionality and performance capability than the final version of the processor, and thus is not representative. For example, this model can accept only about one third of the data inputs to the processor. According to the Navy's 1986 risk assessment for the Update IV Program, use of this model is a high risk.

[13]This processor, designated the Enhanced Modular Signal Processor, analyzes data from acoustic sensors to determine the location and identity of enemy submarines. It offers improved acoustic processing, including more input/output channels, processing power, and operator aids.

Program Oversight Has Occurred

Within the Department of Defense, the management level responsible for overseeing a system acquisition is generally determined by how much the system costs. For the Update IV Program, the Office of the Secretary of Defense has delegated oversight to the Office of the Secretary of the Navy. According to an Office of the Secretary of Defense official, the Update IV Program was delegated because the number of programs the Office of the Secretary of Defense oversees had to be reduced to a manageable level.

In light of the importance of computer technology to the Update IV Program, Navy oversight authorities appear to have focused on this technology in their program reviews. We found briefing documents involving these oversight authorities and the program office which show that such issues as completion of adequate contractor laboratory test facilities, completion of the enhanced acoustic processor, and status of software development have received attention. Additionally, the program office's current approach to developing the Update IV Program has been reviewed and approved by the Navy's Program Executive Officer (Acquisitions). Office of the Secretary of the Navy review of this plan was scheduled for late August 1990, but has been delayed for several months. Should this final approval be granted, however, Navy oversight authorities will be allowing the continued development of software without approved specifications and the planned purchase of 28 systems before full operational testing is completed. Thus, these authorities will not be acting to ensure adherence to Navy software development policies as discussed earlier. According to an official in the Office of the Assistant Chief of Naval Operations (Air Warfare), this software development and testing approach has thus far been approved because they believe that program costs will significantly increase and jeopardize the program if contract production options are not exercised on time.

Conclusions

The Navy is faced with a difficult decision in acquiring a new, technically challenging avionics computer system for its patrol aircraft. If the Navy proceeds according to its current acquisition plan, it will be unable to perform thorough operational testing, and could therefore buy and deploy an expensive system that does not meet mission requirements. On the other hand, if the Navy renegotiates the contract to delay production decisions until it has tested the system and assures that it meets operational requirements, acquisition costs might increase. The Navy has done no detailed analysis, however, to assess the extent of these potential cost increases.

The Navy plans to (1) continue developing software (i.e., coding) before approving detailed requirements for the system, (2) exercise contract options on time and assume an unknown level of risk that the system it buys may not work, and (3) use a model of an enhanced acoustic processor during testing that is not representative of the final version. In our opinion, the Navy's current acquisition approach is unacceptable, causing the Navy to spend almost $500 million on a system that may not meet mission requirements.

Recommendations

We recommend that the Secretary of the Navy direct the Commander, Naval Air Systems Command to (1) halt further software development (i.e., coding) until system specifications are approved, (2) thoroughly justify the need for initial rate production to exceed the four systems originally planned, (3) conduct initial operational testing using actual system components or accurate simulations of them, and (4) conduct full operational testing before making a full rate production decision. In light of the possibility that this may preclude the Navy from exercising existing, fixed-price contract options, we also recommend that the Secretary direct the Commander to thoroughly analyze the cost impact of contract renegotiation, and based on this analysis decide whether the entire Update IV Program is financially viable.

As requested by your offices, we did not obtain official agency comments on a draft of this report. However, we discussed its contents with Navy and Office of the Secretary of Defense officials, and have incorporated their comments where appropriate. Our work was performed between December 1989 and July 1990, in accordance with generally accepted government auditing standards.

As arranged with your offices, unless you publicly announce the report's contents earlier, we plan no further distribution until 30 days from the date of this letter. At that time, we will send copies to the Chairman, Senate and House Appropriations Committees; the Secretaries of Defense and Navy; and to other interested parties. We will also make copies available to others upon request. This report was prepared under the direction of Samuel W. Bowlin, Director, Defense and Security

Information Systems, who can be reached at (202) 275-4649. Other major contributors are listed in appendix II.

Ralph V. Carlone
Assistant Comptroller General

Contents

Abbreviations

GAO	General Accounting Office
IMTEC	Information Management and Technology Division

Objectives, Scope, and Methodology

In October 1989, the Subcommittee on Legislation and National Security, House Committee on Government Operations, expressed interest in the Navy's plans to acquire embedded computer systems for selected anti-submarine warfare systems, and asked that we determine whether (1) the Navy's Update IV Program calls for adequate testing of a new avionics computer system for the P-3 and P-7 aircraft before they are bought, and (2) Navy management is overseeing the development of these embedded systems. This request relates to an overall request from the Chairman and the Subcommittee's Ranking Minority Member to review computer systems that are embedded in Defense weapon systems.

To accomplish our objectives, we reviewed Defense and Navy instructions and standards governing the development, testing, and management oversight of embedded computer systems. We also reviewed Update IV documentation (e.g., acquisition plan, test plans, schedules, and funding requirements) as well as the development/production contract and related documents for the avionics program. Additionally, we interviewed both program officials responsible for managing software development and laboratory officials responsible for monitoring contractor performance. We also interviewed officials at the Navy test activities participating in development and operational testing, and toured contractor software development facilities.

Further, we interviewed officials in the Office of the Secretary of Defense and the Chief of Naval Operations responsible for program oversight, and reviewed documentation associated with the discharge of this oversight responsibility. This work focused on whether and to what extent this oversight specifically addressed the embedded avionics computer system.

We performed our work between December 1989 and July 1990, primarily at the Update IV program office within the Naval Air Systems Command, Arlington, Virginia, and the Naval Air Development Center, Warminster, Pennsylvania. We also visited the Naval Air Test Center, Patuxent River, Maryland; the Navy's Operational Test and Evaluation Force, Norfolk, Virginia; and the contractor's system development facilities in Seattle, Washington.

As requested by the Chairman's office, we did not obtain official agency comments on a draft of the report. However, we discussed its contents with Navy and Office of the Secretary of Defense officials, and have incorporated their comments where appropriate. We conducted our

review in accordance with generally accepted government auditing standards.

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